Consistent Pixel Resolution Characterization of Deep Convective Clouds for Calibration

Conor Haney[a], David Doelling[b], Rajendra Bhatt[b], Prathana Khakurel[a], Benjamin Scarino[b], Arun Gopalan[a]

AMS 104th Annual Meeting, Baltimore, MD, Jan 28– Feb 1

[a]Analytical Mechanics Associates
[b]NASA Langley Research Center

Background

- The NASA Clouds and Earth's Radiant Energy System (CERES) project provides global TOA shortwave and longwave fluxes for the climate community
- The CERES Imager and Geostationary Calibration Group (IGCG) is tasked with inter-calibrating the MODIS, VIIRS, and GEO (geostationary) sensors to a common reference in order to provide consistent clouds and fluxes across the CERES record
- Deep convective clouds (DCC) are used as large ensemble Pseudo Invariant Calibration Sites (PICS) for validating radiometric scaling across imagers
- The DCC-IT (DCC Invariant Target) method monitors the brightest tropical clouds in near overhead sun conditions, as DCC are the most spectrally flat, Lambertian visible targets around the tropopause

DCC Invariant Target Method

- The DCC-IT calibration methodology was initiated almost 20 years ago with the novel approach of Hu et al 2004 for monitoring the CERES instrument calibration
    - The DCC-IT calibration approach has been adopted by GSICS visible sub-group since 2011 and documented as a GSICS ATBD
- The method relies on identifying DCC pixels that meet the following criteria:
    - $BT_{11\mu m} < 205$ K
    - $H_{0.65\mu m} < 0.03$
    - $SDV_{11\mu m} < 1.0$ K

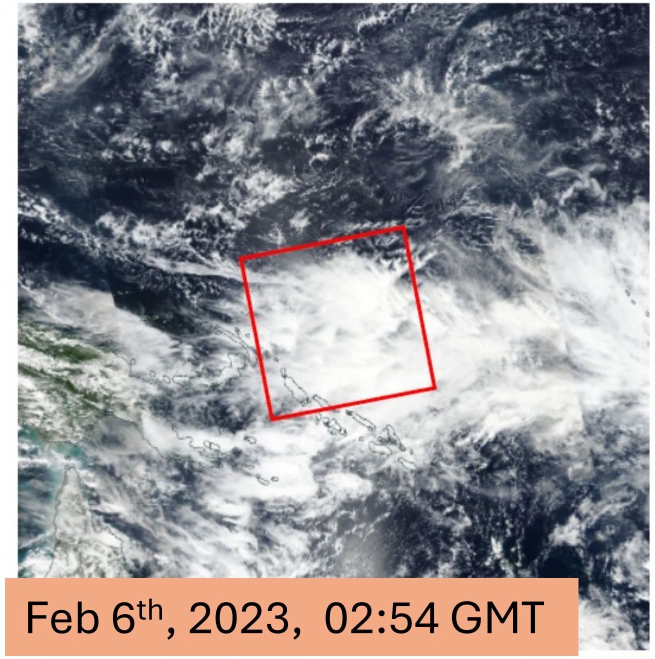
  where BT = brightness temperature, H = spatial homogeneity (3x3 SDV / pixel value)
- The large ensemble of DCC pixel BRDF-corrected reflectances are grouped into reflectance bins on a monthly basis, where the PDF mode (visible) or mean (SWIR) is tracked over time to monitor the stability of the instrument

Motivation

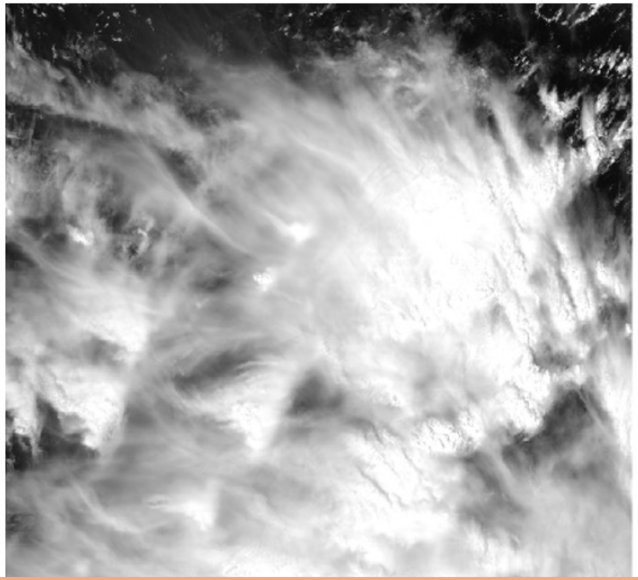
The DCC reflectance PDF is dependent on the DCC pixel identification criteria

- How well do the current DCC pixel identification criteria perform?
- How does the pixel resolution affect the DCC reflectance PDF?
- Is it possible to identify the same DCC cells between sensors that have different pixel resolutions in order to promote inter-calibration?

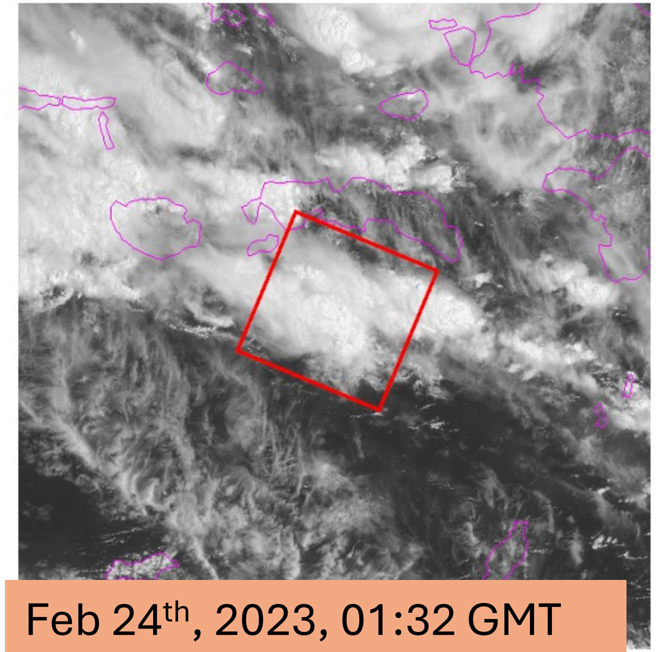
Granule Selection: SNPP-VIIRS and Landsat-8



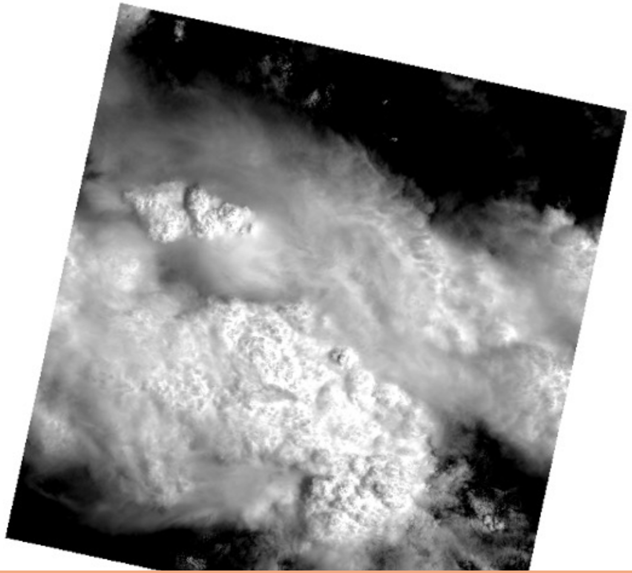
Feb 6th, 2023, 02:54 GMT



SNPP-VIIRS M05 (0.67µm), 750m



Feb 24th, 2023, 01:32 GMT



Landsat-8 OLI/TIRS B4 (0.66µm), 30m

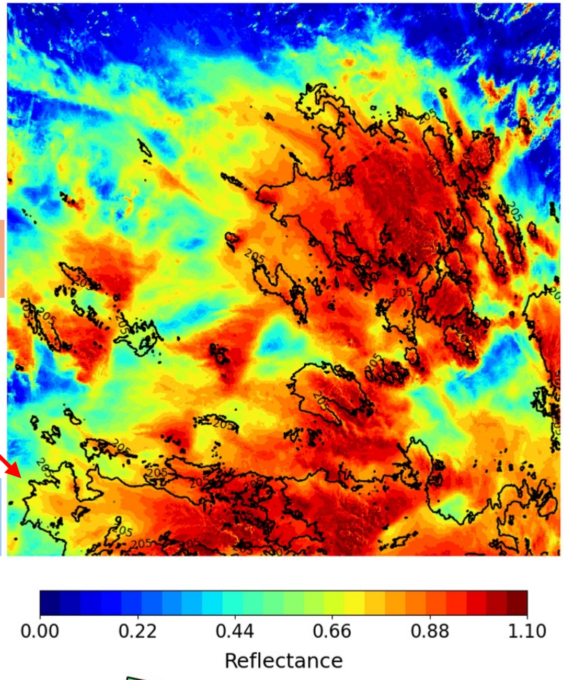
- The Tropical Western Pacific have the greatest frequency of DCC
- Images were identified for SNPP-VIIRS and Landsat-8 OLI/TIRS that observed all stages of the lifecycle of a DCC cell:
  - Still-growing DCC that haven't reached the tropopause yet (these would have warmer BTs)
  - Mature DCC that have reached the tropopause and contain overshooting tops
  - Dissipating DCC with anvils and cirrus blow off (these would have cold BT but are visibly darker than the cores)

DCC Pixel Identification: BT<205K

SNPP-VIIRS, 750m

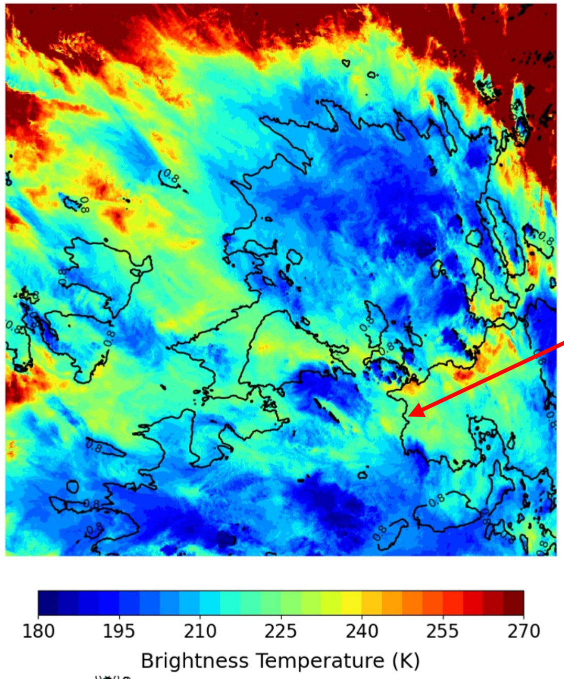
205K contour

M05 0.67µm



0.8 ref contour

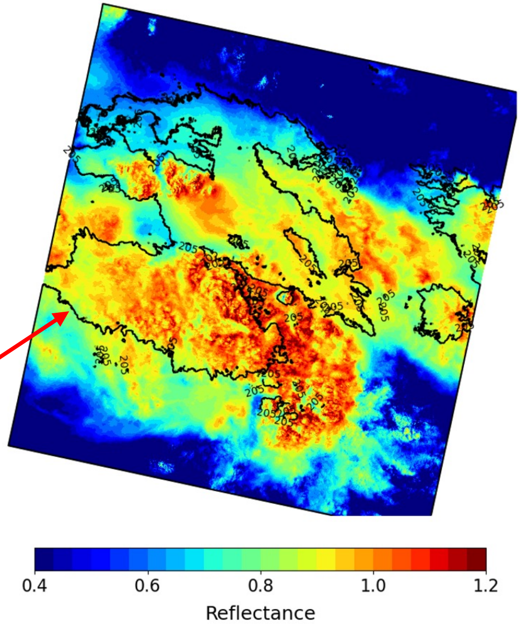
M15 11µm BT



Landsat 8 OLI/TIRS, 30m

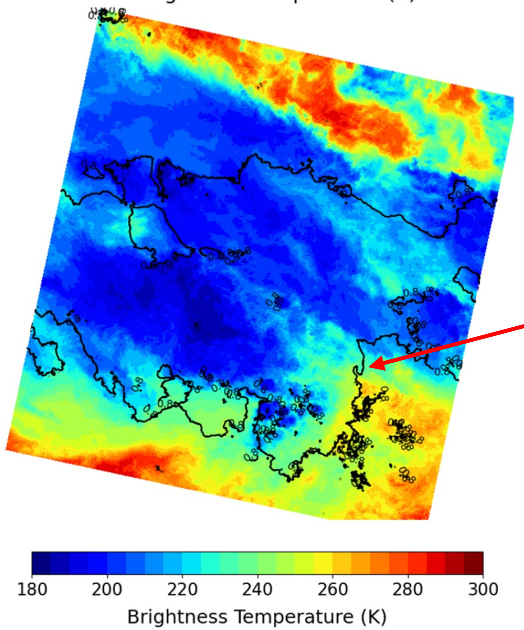
205K contour

OLI B4 0.66µm



0.8 ref contour

TIRS 11µm BT



The contours show that:

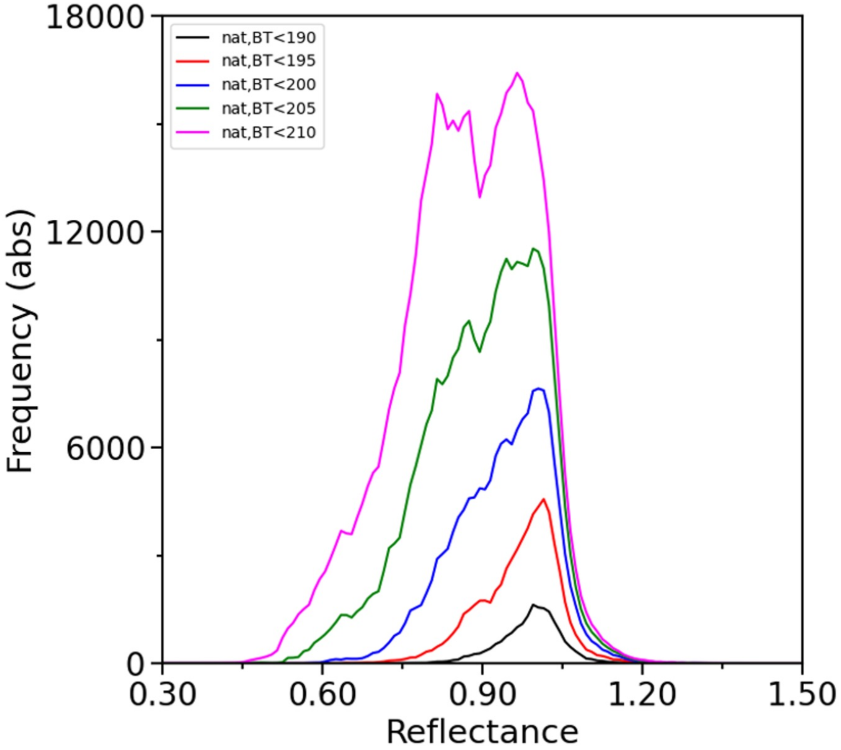
- Not all bright reflectances are within the 205K threshold
- Not all <205K pixels have bright reflectances

What happens if we change the BT threshold?

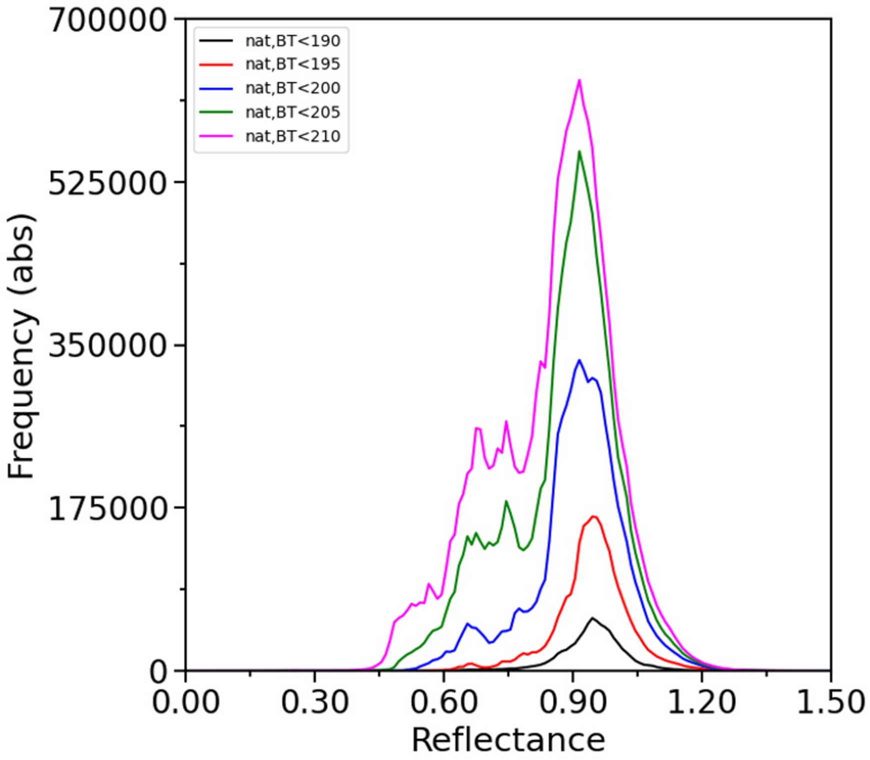
BT Threshold Sensitivity Analysis

Changing the BT threshold can change the shape of the reflectance PDFs

SNPP-VIIRS M05, 750m



Landsat 8 OLI/TIRS B4, 30m



- For both VIIRS and OLI/TIRS, decreasing the BT limit decreases the lower reflectance PDF tail and strengthens the higher reflectance peak, but at the cost of losing a large number of samples
- Decreasing the BT limit increases both the reflectance PDF mean and mode

BT < 190 K

BT < 195 K

BT < 200 K

BT < 205 K

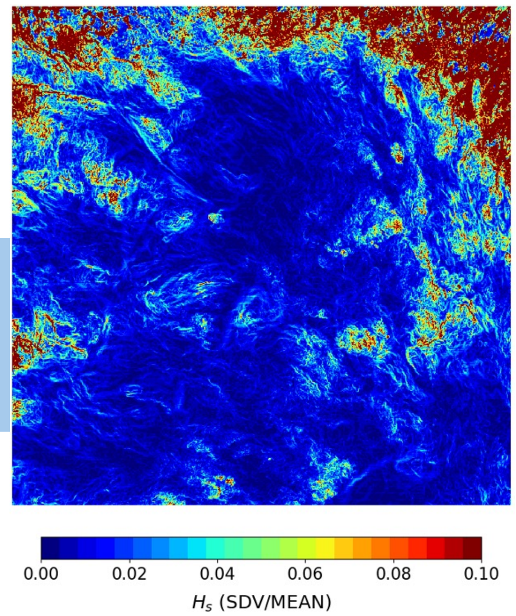
BT < 210 K

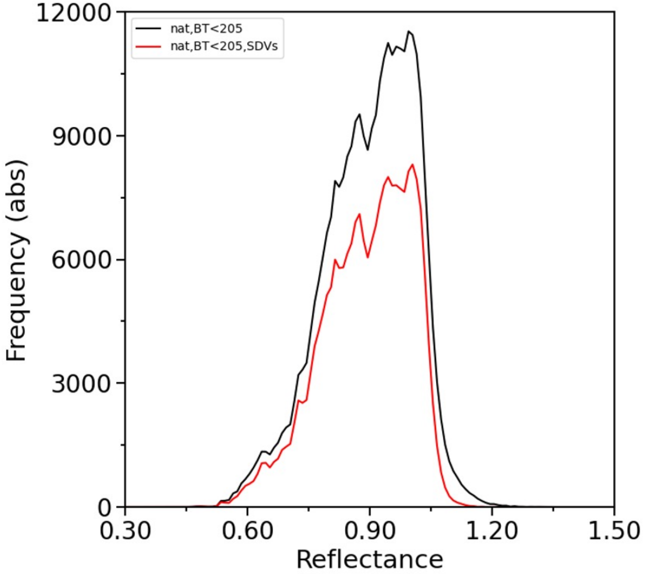
Each color is a 5 K change in BT threshold

DCC Pixel Identification: Spatial Homogeneity

SNPP-VIIRS

M05 (750m) spatial homogeneity map (H_s)



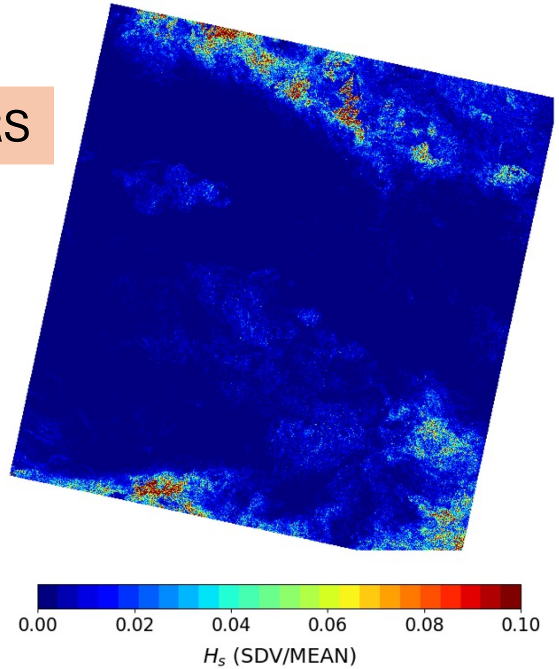


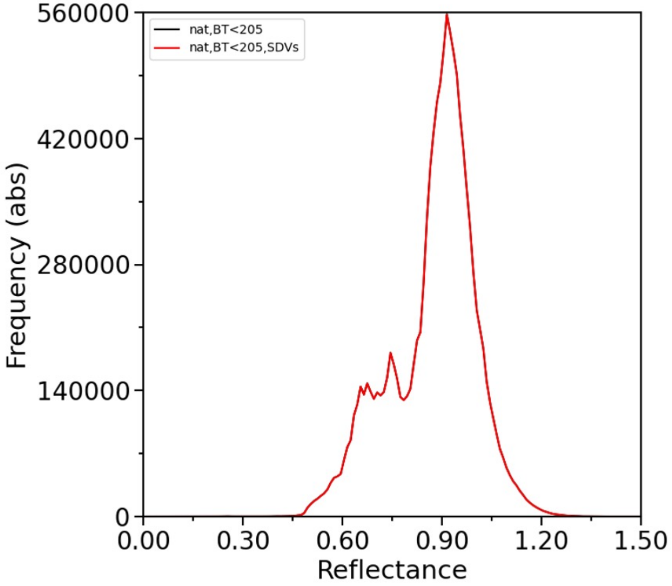
- Intention of visible and IR spatial homogeneity thresholds is to produce a sharper reflectance PDF peak, while reducing the PDF range
- The idea is to remove heterogenous cirrus and cloud edge pixels while maintaining DCC cores

VIIRS:
H_s thresholds remove ~30% of the data, while the PDF shape seems generally the same

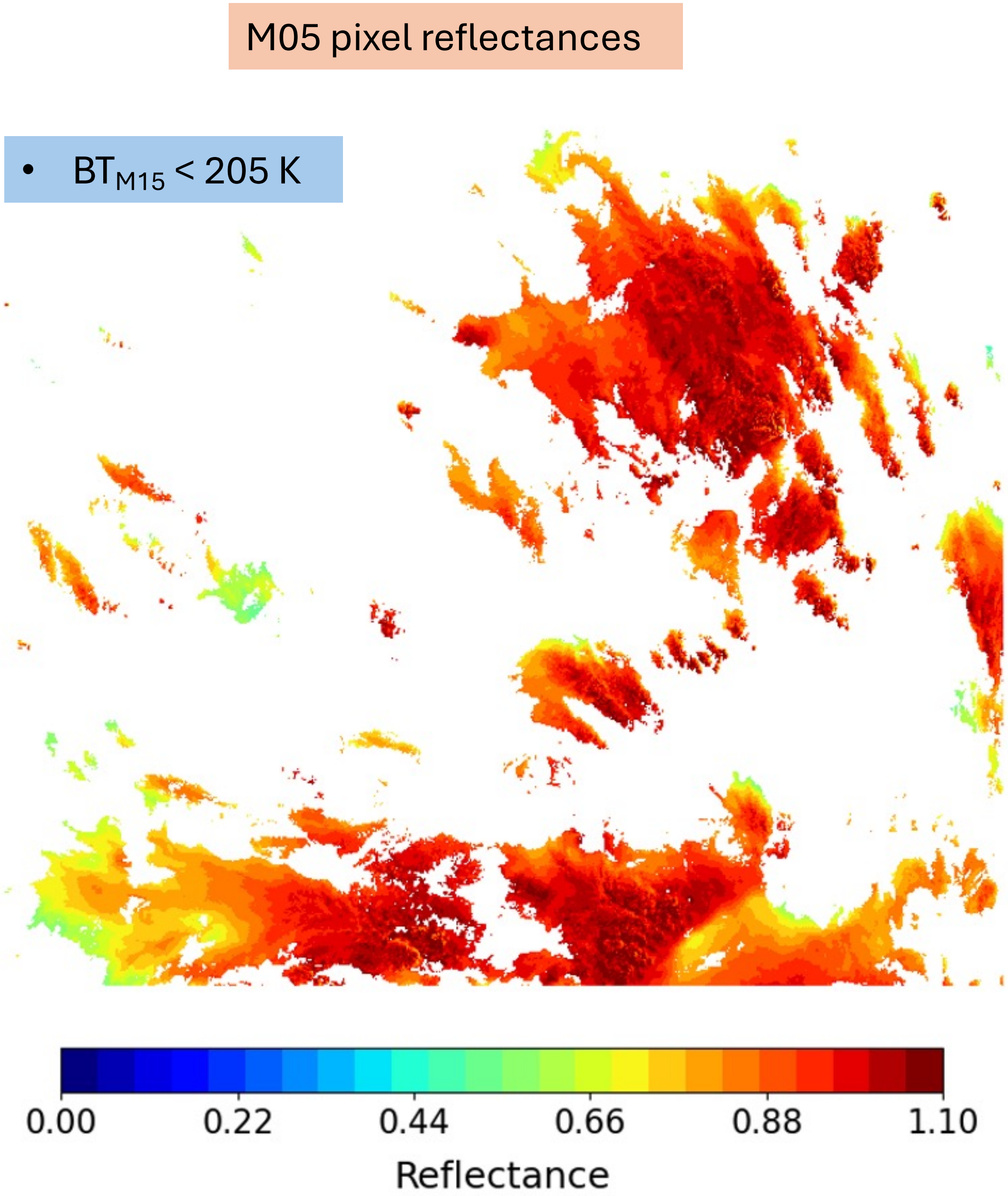
Landsat 8 OLI/TIRS

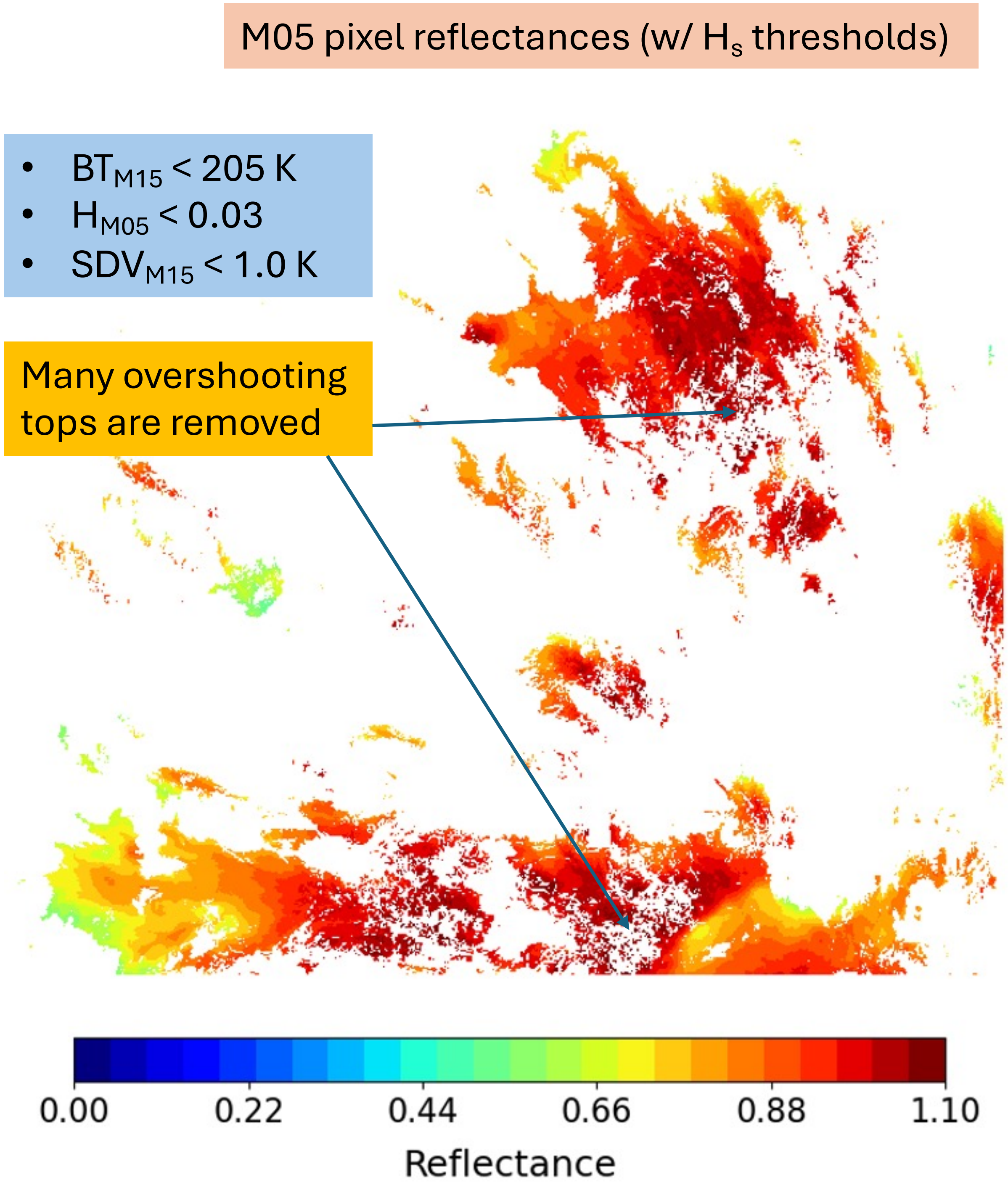
B4 (30m) spatial homogeneity map (H_s)





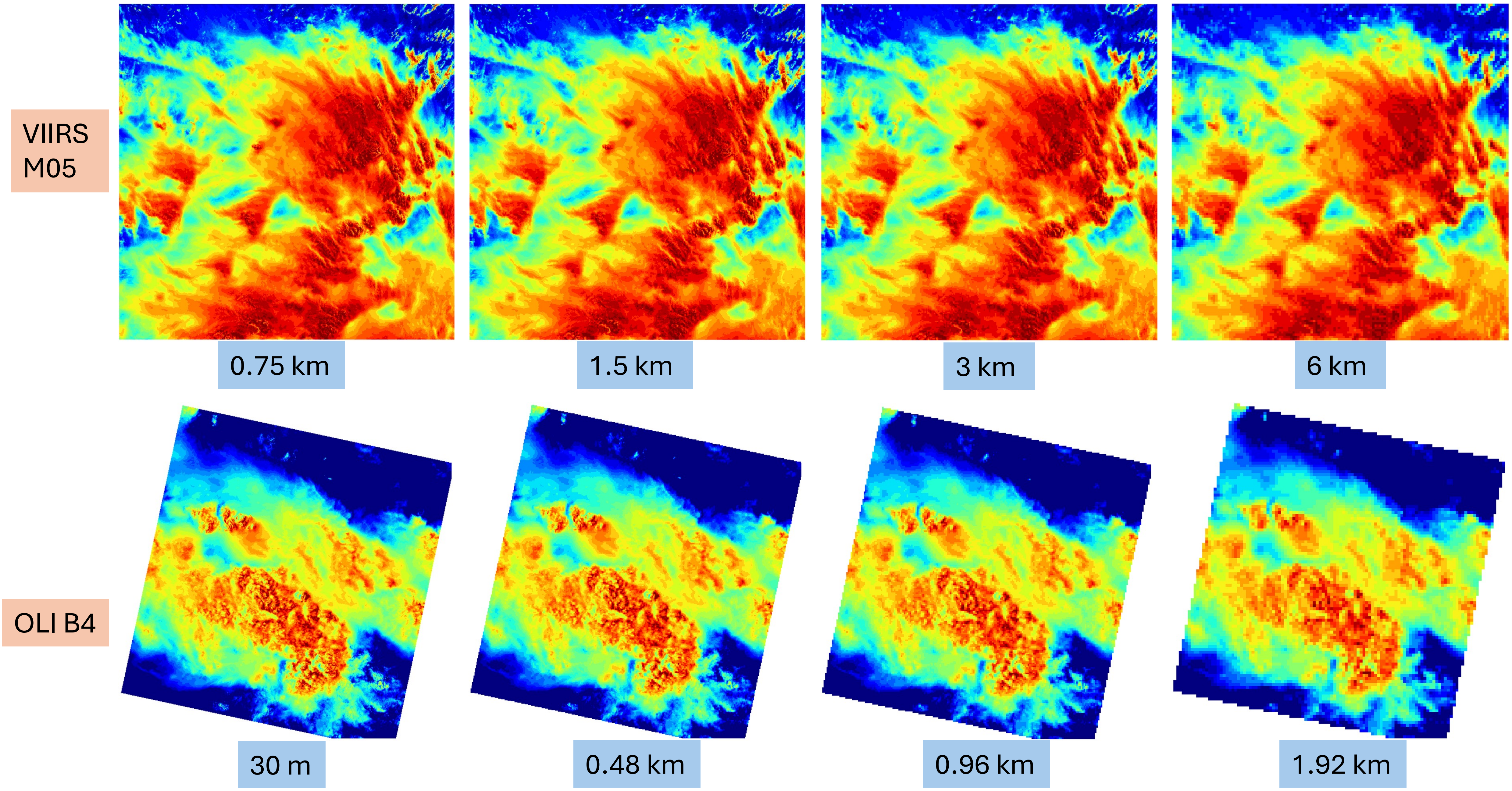
Landsat 8:
The 30m resolution is so small that the pixels generally do not contain mixed scene types such as cloud edges
H_s is not useful at all for 30m, the PDF is virtually the same


M05 pixel reflectances
• BT$_{M15}$ < 205 K
0.00
0.22
0.44
0.66
0.88
1.10
Reflectance


M05 pixel reflectances (w/ H$_s$ thresholds)
• BT$_{M15}$ < 205 K
• H$_{M05}$ < 0.03
• SDV$_{M15}$ < 1.0 K
Many overshooting tops are removed
0.00
0.22
0.44
0.66
0.88
1.10
Reflectance

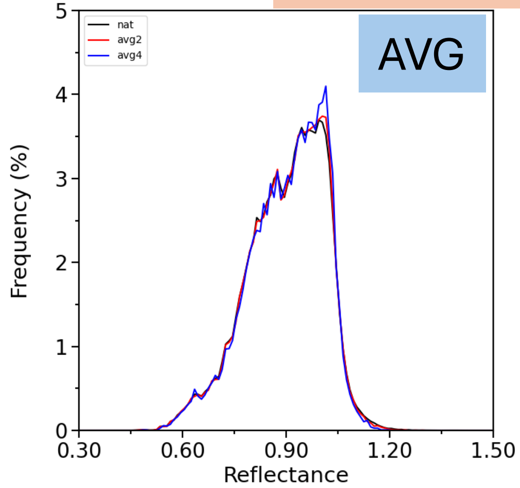
Pixel Resolution of DCC Scenes

Aggregation of native pixel resolutions



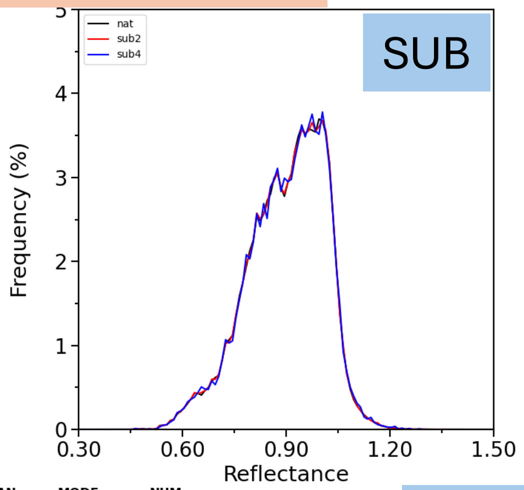
Sub-sampling Impact on PDF Shape

SNPP-VIIRS M05 Reflectance



MEAN	MODE	NUM
0.900	0.995	311843
0.901	1.005	77897
0.902	1.015	19398

M15 < 205



MEAN	MODE	NUM
0.900	0.995	311843
0.900	1.005	78147
0.901	1.005	19555

0.75-km

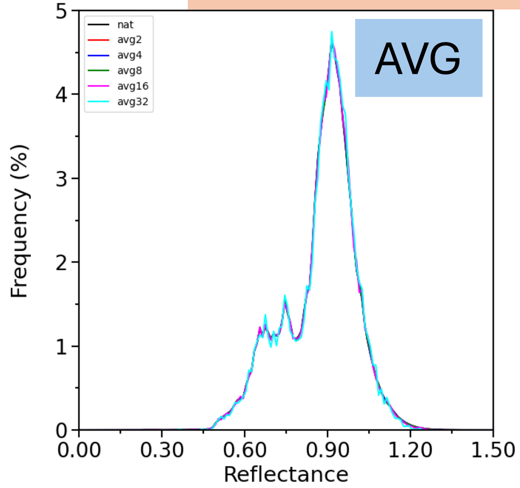
1.5-km

3-km

For VIIRS, >3km is not shown—the PDFs get very noisy

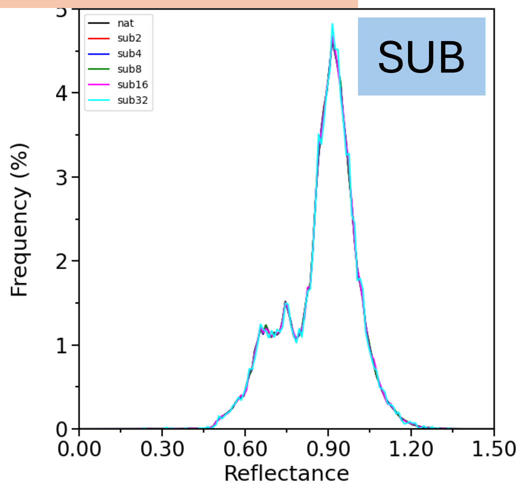
- BT11µm < 205 K

Landsat 8 OLI/TIRS B4 Reflectance



MEAN	MODE	NUM
0.875	0.915	11999209
0.875	0.915	2999998
0.875	0.915	749741
0.875	0.915	187333
0.876	0.915	46779
0.876	0.915	11645

B10 < 205



MEAN	MODE	NUM
0.875	0.915	11999209
0.875	0.915	2999743
0.875	0.915	749948
0.875	0.915	187496
0.876	0.915	46829
0.876	0.915	11714

B10 < 205

30-m

60-m

0.12-km

0.24-km

0.48-km

0.96-km

AVG = Pixel aggregation by averaging

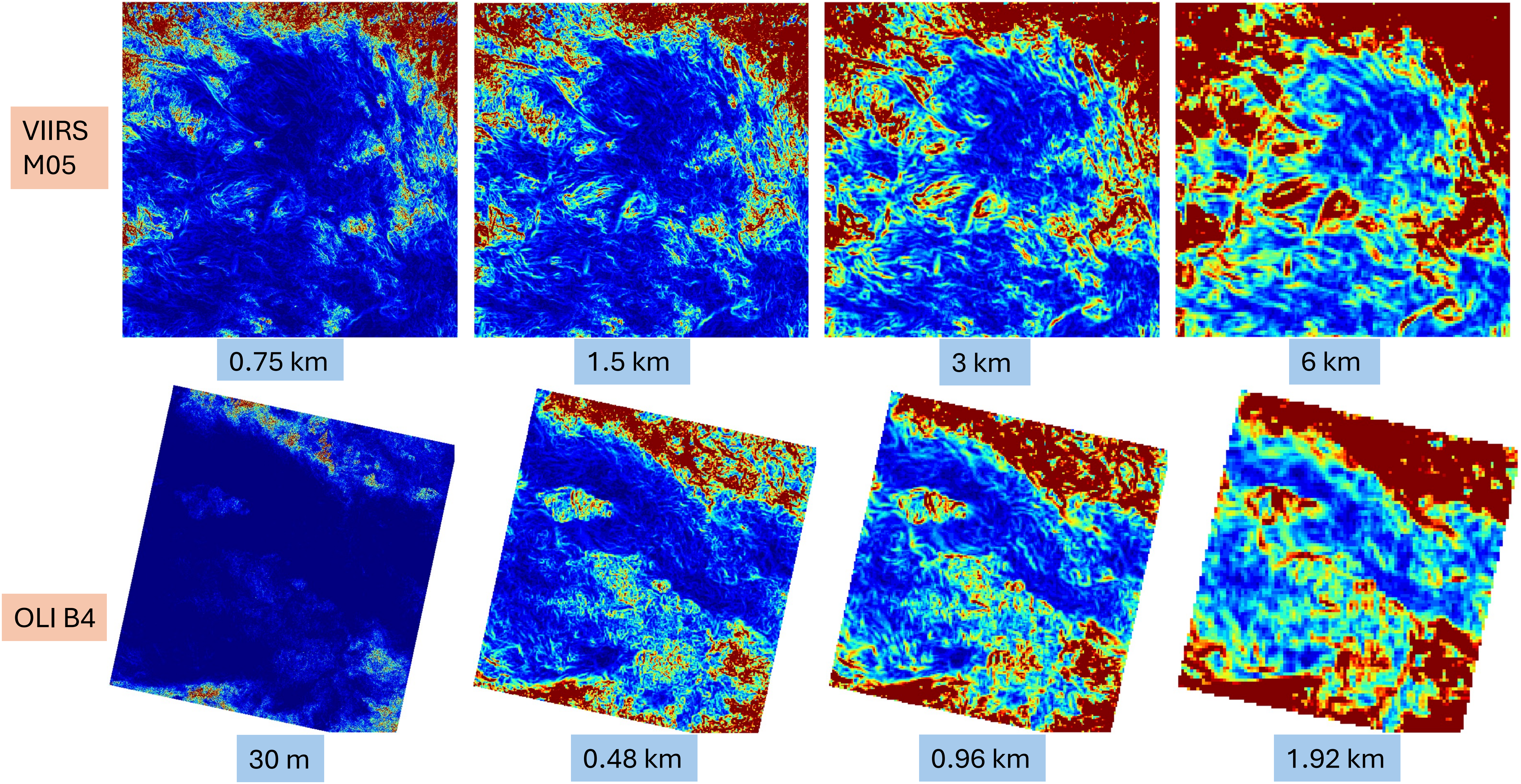
SUB = Pixel aggregation by sub-sampling (1 pixel represents all pixels in the aggregated area)

VIIRS:
- PDF shape remains the same
- Both mean and mode stay nearly the same, regardless if averaged or sub-sampled, with the AVG mode changing by about 2%

OLI/TIRS:
- Both the mean and mode stay the same from native 30m resolution up to 1 km, regardless if AVG or SUB

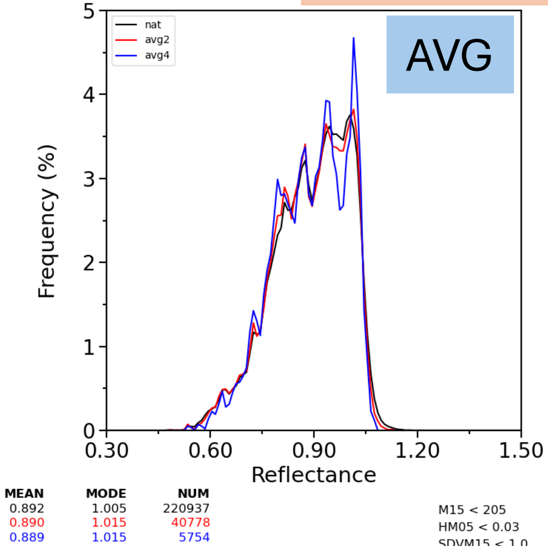
Spatial Homogeneity of DCC Scenes

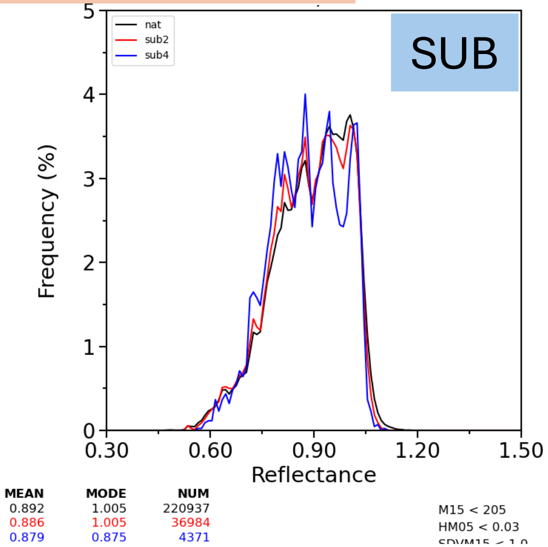
Aggregation of native pixel resolutions



Sub-sampling Impact on PDF using Homogeneity Thresholds

SNPP-VIIRS M05 Reflectance





0.75-km

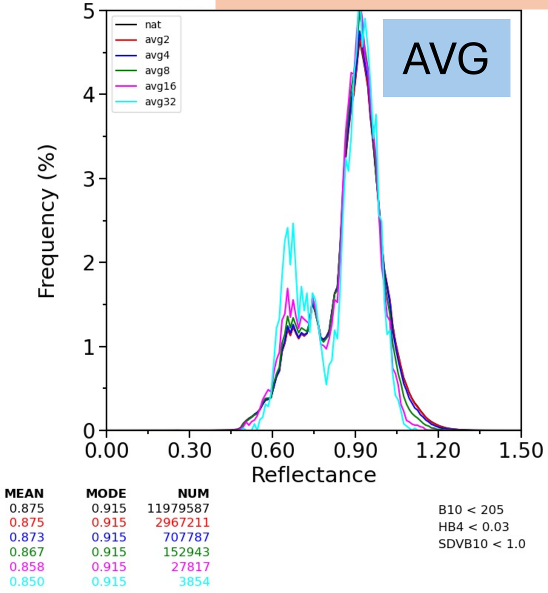
1.5-km

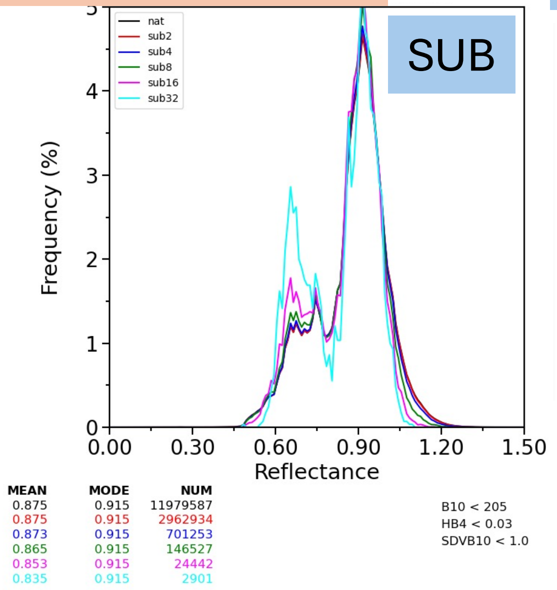
3-km

For VIIRS, >3km is not shown—the PDFs get very noisy

- $BT_{11\mu m}$ < 205 K
- $H_{0.65\mu m}$ < 0.03
- $SDV_{11\mu m}$ < 1 K

Landsat 8 OLI/TIRS B4 Reflectance





30-m

60-m

0.12-km

0.24-km

0.48-km

0.96-km

VIIRS:
Coarser resolutions reduces the range of the PDF, but the dominating peak is now several peaks of varying reflectance, which could be a problem for getting the mode (especially SUB)

OLI/TIRS:
Making the resolutions more coarse retains the same mode while decreasing the mean and reducing the PDF range

SNPP-VIIRS M05						
	Averaging			Sub-sampling		
Avg/Sub Rate	MEAN	MODE	NUM	MEAN	MODE	NUM
x1 (0.75km)	0.892	1.005	220937	0.892	1.005	220937
x2 (1.5km)	0.890	1.015	40778	0.886	1.005	36984
x4 (3.0km)	0.889	1.015	5754	0.879	0.875	4371

Landsat 8 OLI B4						
	Averaging			Sub-sampling		
Avg/Sub Rate	MEAN	MODE	NUM	MEAN	MODE	NUM
x1 (0.03km)	0.875	0.915	11979587	0.875	0.915	11979587
x2 (0.06km)	0.875	0.915	2967211	0.875	0.915	2962934
x4 (0.12km)	0.873	0.915	707787	0.873	0.915	701253
x8 (0.24km)	0.867	0.915	152943	0.865	0.915	146527
x16 (0.48km)	0.858	0.915	27817	0.853	0.915	24442
x32 (0.96km)	0.850	0.915	3854	0.835	0.915	2901

Conclusions and Future Work

- The various lifecycle stages of DCC makes it challenging to identify DCC cells that have reached the tropopause and are maintaining strength
  - High reflectance cloud pixels are not always cold
  - Cold pixels are not always high reflectance
  - Overshooting tops may be spatially heterogenous
- Decreasing the BT limit will focus on DCC cells with higher reflectance, but at the cost of significantly reduced sampling
- A simple $BT_{11\mu m} < 205$ K threshold provides consistent DCC reflectance PDFs for pixel spatial resolutions from aggregation up through 3 km, regardless of averaging or subsampling
- $BT_{11\mu m} < 205$ K with homogeneity thresholding will give consistent DCC reflectance PDFs for pixel spatial resolutions from aggregation less than 3 km
- Pixel resolution not seeming to affect the DCC PDF structure opens the possibility that sensors of different pixel resolutions can be radiometrically scaled using DCC targets
- Future work will prioritize enhancing the current DCC pixel identification criteria